PROCEEDING

INTERNATIONAL SYMPOSIUM

Recent Drying & Storage Technology of Foods and Agricultural Products

Dongguk University

November 3, 2001

Seoul, Korea

Organized by
Korean Society for Food Engineering
Korean Society of Postharvest Science & Technology of Agricultural Products

Sponsored by
Korea Research Foundation
Korean Federation of Science and Technology Societies

Control of Arthropod Pests after Harvest using CA, GRAS Fumigants or Radio Frequency Heating

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With increased restrictions on the use of methyl bromide fumigation, there is interest in developing alternative methods for postharvest insect control during storage of dried fruits and nuts, and as quarantine treatments to allow for international trade of fresh produce. Controlled atmospheres with elevated carbon dioxide and reduced oxygen concentrations; fumigation with natural, volatile compounds; and rapid heating with radio frequency energy are three potential alternatives for insect control.

Controlled Atmospheres

Controlled atmospheres (CA) have been used for many years for the control of stored product pests in grains (DeLima, 1990), and are used during storage of some dried fruit and nuts to control insect populations. Insecticidal controlled atmospheres (ICA) generally contain $\geq$ 20 % CO_2 and/or $\leq$ 1 % O_2, depending on the temperature. These atmospheres are generally outside the optimum range for storage or transport of fresh fruits and vegetables, and often induce stress in the commodity. In fact, product tolerance is usually the limiting factor in the development of effective insecticidal CA treatments. There has been considerable research in this area (Mitcham et al. 2001), but to date there are no approved CA quarantine treatments.

CA treatments are generally more effective at higher temperatures, but some commodities do not tolerate exposure to such temperatures. Use of insecticidal CA at temperatures of 5°C or lower generally requires a long exposure to achieve complete mortality. However, low temperature CA could be applied during marine transit. A 13 day treatment with 45 % CO_2 (11.5 % O_2) at 2°C or lower has been developed for control of Pacific spider mites, western flower thrips and omnivorous leafrollers on table grapes (Mitcham et al. 1997). While table grapes tolerate this treatment, exposure to insecticidal atmospheres for this length of time, even at low temperatures, would not be tolerated by many fresh commodites.

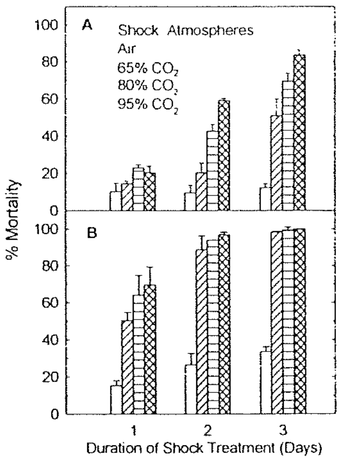

Fig. 1. Mortality of Pacific spider mites following 1, 2 or 3d exposure to shock atmospheres (65 to 95% CO_2) (A) and shock atmospheres plus 18d in air at 0°C (B).

In an effort to reduce phytotoxic effects and to development treatments that use atmospheres easier to achieve in marine containers, sequential CA treatments were developed. The sequential treatments include a short (0.5 to 3 d) shock treatment at an extreme atmosphere followed by a longer (12 to 18 d) exposure to a mild atmosphere or air at low temperature. The short shock treatment and mild follow-up treatment have been demonstrated to have synergistic effects on the mortality of CA-resistant Pacific spider mites (Fig. 1). Sequential treatment combinations of 1 d at 80 % CO_2 + 18 d of 20 % CO_2 with 5 % O_2; 2 d of 80 % CO_2 + 18 d at 8 % CO_2 in air; and 3 d of 95 % CO_2 + 18 d of cold storage in air, all at 0°C, resulted in complete mortality of all lifestages of Pacific spider mites (Zhou and Mitcham, 1998). It appears that the physiological damage to arthropods caused by the shock treatment cannot be repaired when the shock treatment is followed by a long-term mild treatment or a very low temperature treatment; rather, the damage is deepened gradually to an irreversible level at which the arthropods die. The short exposure to extreme atmosphere conditions would be tolerated by more commodities, and could be accomplished on land prior to marine shipment.

GRAS Fumigants

Investigations into the use of naturally occurring plant volatiles as potential fumigants for postharvest treatment of arthropods have increased due to tighter restrictions governing the use of methyl bromide as mandated by the Montreal Protocol of 1991. Fruits produce naturally many volatile compounds that are important for aromatic and flavor characteristics (Nursten 1970). Many plant volatiles such as ethyl formate and acetaldehyde have been shown to offer resistance to plant pathogens and arthropod pests (Aharoni et al. 1980, Bano et al. 1981, Yuen et al. 1995). One important advantage of using volatiles for fumigation is that the residues found on treated commodities are often in trace amounts (Aharoni et al. 1980, Desmarchelier and Ren 1999), and treatment methods are very similar to methyl bromide fumigation.

The Food and Drug Administration (FDA 1979) reviewed the use of ethyl formate as a flavoring agent and characterized this compound as generally recognized as safe (GRAS). Ethyl formate occurs naturally in a large variety of products, and is a natural component of grapes and wine (Peynaud and Ribereau-Gayon 1971, Hiroyasu et al. 1972). Acetaldehyde is also considered GRAS and is a natural component of fruit. Of course, effective concentration are much higher than those found naturally in fruit tissues.

Both acetaldehyde and ethyl formate are effective against a wide range of insect and mite pests; however, the effective concentrations are phytotoxic to some plant material. Green leaves and stems are particularly susceptible to damage. In addition, absorption and metabolism of these volatiles by plant material can reduce the insecticidal effect and therefore, the amount of fruit per volume of treatment container must be considered during treatment development. For harvested strawberry, we determined that the concentrations of acetaldehyde and ethyl formate needed for control of thrips and mites were not tolerated by the fruit calyx (Table 1). While 4% acetaldehyde gave nearly 95% mortality for both western flower thrips and two-spotted spider mites, the strawberry

Table 1. Response of western flower thrips, two-spotted spider mites, and strawberry fruit to fumigation with acetaldehyde for 1 hour at 24°C.

Acetaldehyde (%)	Mortality (%) Western Flower Thrips	Mortality (%) Two-spotted Spider Mite	Calyx Damage[z]	Berry Damage[z]
0	5.1	10.6	1.8b	1.1a
1	12.3	14.6	1.6a	1.2a
2	89.0	39.9	1.7ab	1.2a
3	93.8	73.6	2.7c	1.2a
4	95.1	93.3	3.3d	1.2a

There was a 13% load factor (weight of strawberries per volume of fumigation chamber).
[z]Score: 1=none; 2=slight; 3=moderate; 4=severe

calyx did not tolerate greater than 2% Aa. For table grapes, tolerance to ethyl formate appears to be within the effective insecticidal range. Phytotoxicity to grape clusters is seen as browning on the stems and rachis. A similar type of damage occurs as a result of methyl bromide treatment. Table grapes tolerated a 1 hour fumigation with 500 µl of ethyl formate and this treatment was effective against Pacific spider mites, western flower thrips and omnivorous leafroller eggs, but not omnivorous leafroller pupa (Table 2). A combination of fumigants with CA can often increase efficacy, especially when the fumigation is followed by exposure to insecticidal CA.

Table 2. Percent mortality of Pacific spider mites, omnivorous leafrollers and western flower thrips treated with 100, 250 or 500 µl ethyl formate for 1 or 3 hours at 24°C without plant material present.

Species	Lifestage	Ethyl Formate (µl) 0	100	250	500	100	250	500
			1 hour			3 hours		
Pacific Spider Mite	adult	5.8	22.2	70.4	100	90.4	99.2	100
	deutonymph	3.5	20.6	96.6	100	96.2	100	100
	protonymph	1.0	26.8	100	100	97.8	100	100
	larva	0.9	49.2	100	100	100	100	100
Omnivorous Leafroller	pupa	0	0	20.0	60.0	90.0	100	100
	eggs	0	0	0	100	13.8	100	100
Western Flower Thrips	adult	9.0	100	100	100	100	100	100
	pupa	9.1	100	100	100	100	100	100
	larva	7.5	100	100	100	100	100	100

Radio Frequency Heating

Heating produce with radio frequency (RF) energy is receiving increased attention as a possible alternative method of insect control in harvested produce. This method has the advantages of conventional heat treatments (non-chemical method, safe to use, effective against many pests) without the disadvantage of slow heat transfer into the commodity center where many pests reside (Fig. 2) (Tang, et al., 2000). A major advantage of RF treatments over conventional thermal methods is that the treatment times are very short compared to conventional methods. The short treatment time makes it possible to design continuous treatment systems to allow processing of large quantities of products in a short period of time, a tremendous advantage over batch-type fumigation or conventional heating. The susceptibility of target pests increases as the speed of heating increases. In addition, the dielectric loss factor ε″ of insect pests in the RF region is larger than for host materials (Fig. 3) (Tang et al., 2000), particularly dry nuts, which may lead to preferential heating of insects (Nelson, 1996; Ikediala et al., 2000; Tang et al., 2000).

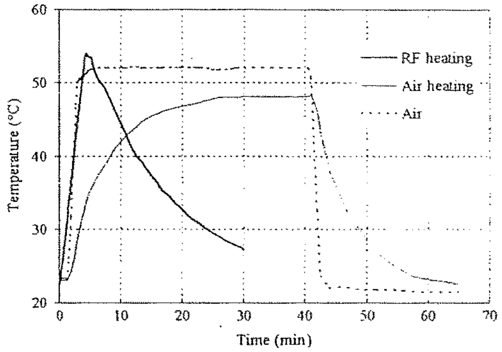

Fig. 2. Heating and cooling curves for in-shell walnut kernel when subjected to forced hot air (air temperature, 53°C; air velocity,1m/s) and RF treatment, then cooled.

RF Treatment of Walnuts

Our research on in-shell walnuts has indicated that a 3-min RF treatment with 27 MHz energy resulted in 100% mortality of codling moth (Wang et al., 2001) and Navel orangeworm larvae and did not cause any negative effects to walnut quality.

Treated walnuts were subjected to objective and sensory evaluations. There was no effect of RF treatment on shell or kernel color, kernel texture or sensory quality; however, treated nuts had significantly lower moisture content. Accelerated shelf-life studies were conducted to determine the effects of RF treatment on the potential of walnuts to become rancid during long-term storage at 4°C. The peroxide and fatty acid values indicated that the RF treatments did not significantly affect walnut rancidity. In fact, our studies indicate that short-time RF treatment may reduce walnut rancidity and lipoxygenase activities in walnuts and almonds (Buranasompob, 2001). The decrease in moisture content may provide some additional benefit in reducing microbial growth during storage, thereby reducing the risk of product spoilage.

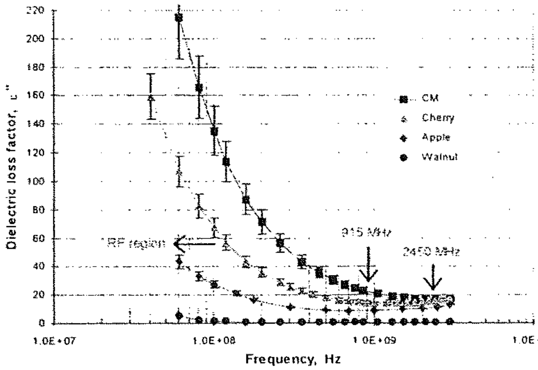

Fig. 3. Dielectric loss factors of apple, cherry, walnut and codling moth larva (CM) at RF and microwave frequencies.

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기체 환경 조절, GRAS 훈증제 및 Radio Frequency 가열을 이용한 수확 후 과일과 견과류의 해충 Arthropod 의 제어

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훈증제인 methyl broide 의 사용에 대한 제한이 강화되면서 신선과채류의 국제교역에서 허가되기 위한 검역의 처리로서 건조된 과일이나 견과류의 수확 후 해충의 제어를 위해 처리하는 방법들에 대한 관심이 날로 늘고 있다. 최근 해충의 제어를 위한 세가지 방법으로 이산화탄소를 증가시키고 산소를 감소시키는 기체 환경 조절 (CA), 천연의 휘발성 성분의 훈증 및 radio frequency (RF)에너지를 이용한 신속한 가열방법이 검토되고 있다. CA 는 고농도부터 저농도의 CO2 의 처리 농도와 처리 기간을 병합하여 실시하는 방법들이 이용되고 있는데 이들 일련의 조합된 처리나 높은 농도의 CO2 를 낮은 온도에서 처리하면 더욱 효과가 있는 것으로 보고되고 있다. GRAS 훈증제로는 과일에서 발생되고 있는 휘발성 물질로 아세트알데히드와 에틸포메이트의 이용이 검토되고 있는데 다양한 해충에 효과가 있다. 현재 딸기와 포도에서 해충 제어에 효과가 보고되고 있으며 CA 처리와 함께 dlef 의 훈증을 실시하면 더욱 효과를 높일 수 있는 가능성이 있다. RF 가열은 재래식 가열 방법과 달리 대상 품목들이 저장되어 있는 공간의 중심에 까지 빠른 시간 내에 열이 전달되기 때문에 가열 처리 시간을 매우 짧게 할 수 있는 큰 장점이 있어서 건조 견과류에서 검토되고 있다. 특히 RF 가열로 인해 호두의 산패와 아몬드와 호두에서의 지방산화 효소인 lipoxigenase 의 활성의 감소 가능성이 있고, 아울러 수분 감소로 미생물의 생육을 저해하여 부패의 위험을 줄일 수 있는 효과가 있다.